Statement of Work

Conformal Ablative TPS Manufacturing Scale-Up

Advanced Ablative Technology Project

August 27, 2013

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

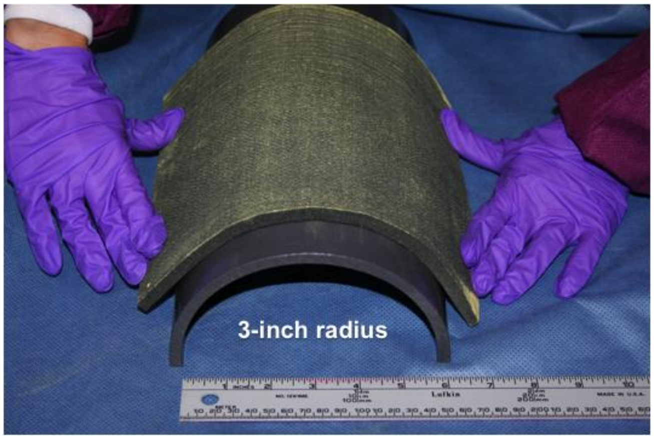
TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 GENERAL INFORMATION

NASA has identified the need for research and technology development in the area of deployable entry systems capable of supporting Exploration Class missions. One element of a deployable entry system is the development of a conformal ablative TPS technology targeting missions requiring peak heat-flux around 250 W/cm^2. A conformal TPS over a rigid aeroshell has the potential to solve a number of challenges faced by traditional rigid (low strain-to-failure) TPS materials.

NASA believes the compliant (high strain to failure) nature of conformal ablative materials will allow easier integration of TPS with the underlying aeroshell structure and enable monolithic-like configuration and larger segments (or parts) to be used. By reducing the overall part count, the cost of installation (based on cost comparisons between blanket and tile materials on the Space Shuttle) should be significantly reduced.



Both conformal and flexible carbon-felt based materials have recently been successfully tested in aerothermal environments above 500 W/cm^2 under various NASA programs. However, the current capabilities goal for conformal TPS is similar to an MSL design reference mission (~250 W/cm^2) with matching pressures and shear environments.

In general, the materials under development are low density (~0.28 g/cm^3) and are fabricated in a process similar to Phenolic Impregnated Carbon Ablator (PICA) – US Patent #5,536,562 Tran, et al. July 16, 1996. As a means of creating a conformal TPS the materials under development at NASA utilize a flexible carbon felt as the substrate instead of rigid carbon foam. In a process similar to the fabrication of PICA, the felt is then infiltrated with a modified phenolic-based solution. The resulting material is NASA's Conformal-PICA (C-PICA)

Based on successful arcjet results from recent test campaigns, NASA has chosen C-PICA for process scale-up. This involves contracting with a contractor to demonstrate uniform infiltration of the resin system into a nominal ~1-inch thick carbon felt that is at least 1 sq. meter in area. Following initial fabrication by the contractor a series of material property and arcjet tests will be conducted for comparison of contractor-produced material to NASA produced samples.

Successful engagement with Industry is the primary goal for this project. This is to be further demonstrated in the fabrication of a sub-scale Manufacturing Demonstration Unit (MDU) on the order of ~2-meter diameter. Fabrication of the MDU will allow system level technology maturation and demonstration. This exercise is critical in the development of processes and identifying a contractor qualified to potentially provide flight hardware. At the end of 2014, the Conformal Ablator project anticipates having matured a conformal ablator TPS to TRL-5 by testing in a relevant environment, developing the model to predict behavior, and demonstrating manufacturability on a large-scale system. In FY 2015 the contractor may further be asked to fabricate conformal TPS for a full-scale MDU on the order of ~3-meter diameter.

The current materials under development are considered Government sensitive information/proprietary. Development of these materials is ITAR and thus is restricted to US companies only. ***This is not a technology transfer*****.** *Upon award of a contract, specific processing details will be shared with the contractor via a non-disclosure agreement. For the purpose of this RFP, a generalized overview of the process to be scaled-up can be obtained by request however release is subject to approval by NASA.*

1.2 SCOPE AND OBJECTIVES

The contractor shall have the **existing** in-house experience, infrastructure and capabilities to manufacture the selected conformal ablative material. Specifically, the contractor must have vacuum infiltration equipment capable of handling a solution of phenolic and ethylene glycol and vacuum/curing ovens capable of up to 170-200°C and 1 Torr.

The contract will consist of 3 Phases, and 4 separately priced Optional Tasks that may be exercised separately or together after contract award.

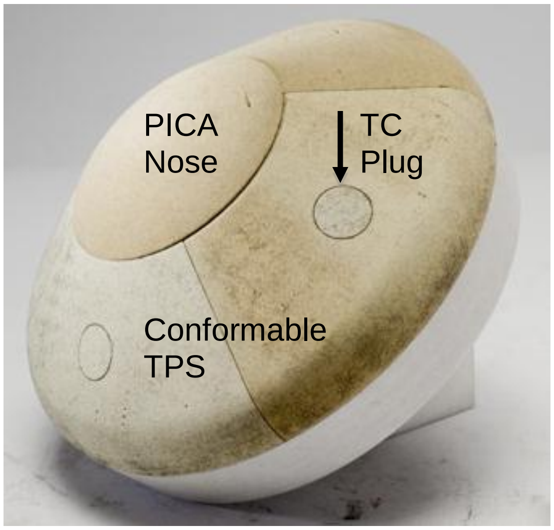


Figure 1. Illustration of a SPRITE test article.

Phase 1 - The contractor shall submit a draft Manufacturing Data Book that details their step-by-step order of operations for processing C-PICA of at least 1 sq. meter, illustrating the specific contractor-owned equipment that will be used during processing, detailed TPS mold designs and machining steps (see Section 5.0 DR-001). A draft of the Data Book will be due approximately one month after contract award, with a final version due at the end of Phase 3.

Phase 2–Following NASA review of the draft of the Data Book, the contractor shall fabricate flat conformal ablator panels to be used for material property testing as well as molded and machined articles for arcjet testing in a SPRITE[1] configuration (55°, 7.3-in diameter), Figure 1. Materials for the arc jet test specimens and thermocouple plugs shall be processed in conically shaped molds in a process identical to that, which will be used for the large-scale articles. **For Phase 2 only, NASA will provide three Teflon TPS molds for contractor processing of SPRITE articles.** In addition to fabricating articles for material property testing, the contractor may be requested, as an additional Option, to conduct material property testing described in Section 5 and provide the data to NASA (DR-002).

Phase 3 –Following successful fabrication of material property and SPRITE test articles and approval by NASA, the contractor will proceed with manufacturing and machining of large-scale articles for application to the **sub-scale** MDU. The Full-scale MDU is shown in Figure 2. The sub-scale MDU will be of the same dimensions as the full-scale unit but only 3 of 12 TPS segments plus the spherical nose section are required under this task. Design concepts for these sections are shown in Section 6. NASA will provide drawings of the TPS segments and nose section before this Phase begins. The contractor shall design separate TPS molds for the nose and petal segments, procure/fabricate the MDU molds and procure all necessary chemicals/raw materials for TPS processing. The contractor shall supply NASA with machined specimens (per the Hardware Requirements List, Section 1.3.2). NASA personnel will perform installation of TPS to the MDU structure.

TASK OPTIONS

Option 1– If exercised, the contractor shall machine materials properties test specimens, conduct the properties testing, and report the results.

Option 2 – If exercised, the contractor shall design and fabricate a bonding structure for assembly of the sub-scale MDU. The structure shall support the nose section and 3 TPS petals. The structure shall be fabricated from materials to which TPS segments can be bonded.

Option 3 – If exercised, the contractor shall utilize its scaled up infiltration equipment to infiltrate a NASA provided carbon felt substrate that is ~0.9x0.9-meter and 8-mm (3-inch) thick, molded over the nose segment of the MDU hardware.

Option 4 – If exercised, in FY 2015 the contractor shall fabricate a complete set of TPS segments (1 nose and 12 petals) for a full-scale MDU. NASA personnel will perform installation of TPS to the MDU.

---

[1] Empey, D. M., Skokova, K.A., Agrawal P., Swanson G., Prabhu, D.K., Peterson K. H., and Venkatapathy E., "Small Probe Reentry Investigation for TPS Engineering (SPRITE)", proceedings , 8th International Planetary Probe Workshop, Portsmouth, VA, 6-10 June 2011.

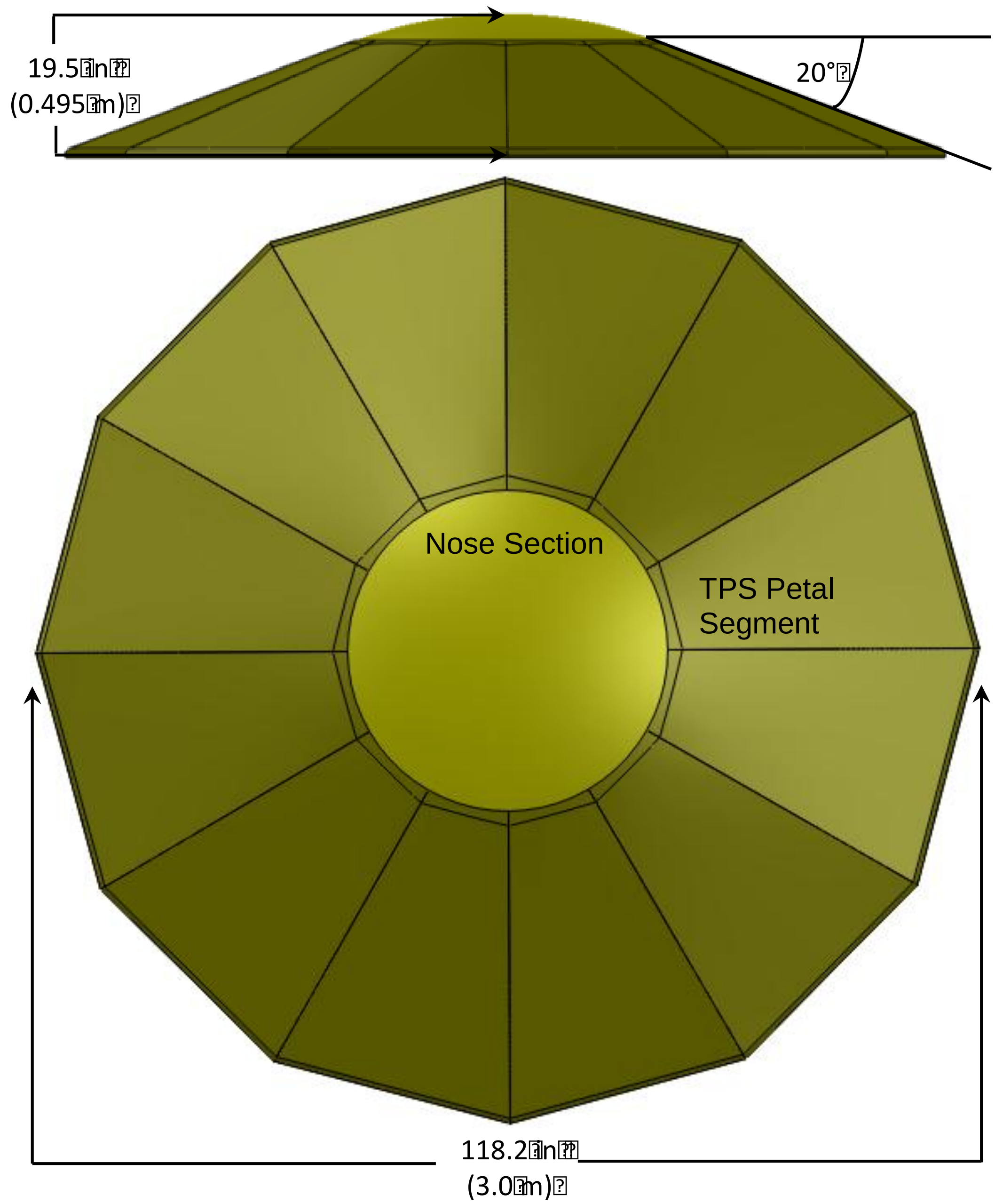


Figure 2 – Schematic of Full-Scale Manufacturing Demonstration Unit (MDU).

Specific requirements for contractor capabilities are outlined below and in Section L of the RFP. Responses must also address the more detailed narrative of requirements given in the description of Deliverables, Section 1.3.

Selected contractor shall:

1. Have current capability in heat shield relevant (aerospace grade) TPS manufacturing:
    a. Floor space, infiltrating vessels and vacuum/ovens necessary manufacture the proposed TPS to the 1-m scale
    b. Personnel experienced in making aerospace grade materials
    c. Personnel experienced in designing necessary tooling needed to make a MDU
    d. Personnel experienced in appropriate Non Destructive Evaluation (NDE) to evaluate material uniformity
    e. Associated product assurance certifications and processing equipment necessary to do so
    f. Certifiable process procedures and specifications
2. Have experience manufacturing *phenolic*-based polymer composites
3. Have experience in working with carbon felts and felt composites
4. Have experience infiltrating resin/solvent into parts >1-m diameter; materials will need to be processed in molds with complex curvature
5. Have the ability to **vacuum infiltrate** and then **remove** large volumes of solvent (*ethylene glycol*) from infiltrated parts prior to and/or during curing (Typical cure conditions 170-200°C and 1 Torr)
6. Ability to conduct or procure NDE of TPS prior to delivery to NASA.
7. Ability to procure necessary chemicals and conduct appropriate quality checks
8. Ability to procure necessary felt materials and conduct appropriate quality checks
9. Ability to take NASA-provided processing specification to scale up infiltration process as needed.
10. Technical feasibility of offered material scale-up process

1.3 DELIVERABLES

The timeframe for completion of deliverables plus all options, if exercised, is 2 years. NASA understands that this scale-up task is a best effort on the part of the contractor and that further process optimizations may be required in partnership with NASA.

1.3.1 Data Deliverables

A description of the required data deliverables is provided in Table 1. Detailed descriptions are in Section 5 of this document.

Table 1 – Data Requirements List

Task	DR #	Title	Due Date
Phase 1	DR-001A	Preliminary Draft Manufacturing Data Book	Nov 30, 2013
Option 1	DR-002	Conformal TPS Material Properties	April 30, 2014
Phase 3	DR-001B	Final Manufacturing Data Book	Sept 30, 2014

1.3.2 Hardware Deliverables

A description of the required hardware deliverables is provided in Table 2. Detailed descriptions (with specimen dimensions) can be found in Section 6 of this document. **All hardware deliverable materials (with the exception of HR-04) are to be fabricated using "1-inch" Morgan carbon felt**. NASA will provide molds/tooling for HRL items 01B and 01C. For HRL items -02A and -02B the contractor will design and procure or fabricate the tooling.

Table 2- Hardware Requirements List

	HR #	Sample Type	Quantity	Due Date
Phase 2	HR-01A	TPS for Material Properties Testing (15"x15"x~1"thick)	2	Jan 15, 2014
	HR-01B	SPRITE TPS Segments*	12	Jan 15, 2014
	HR-01C	SPRITE TC Plugs	10	Jan 15, 2014
Phase 3	HR-02A	MDU TPS-Gore Segments	3	Jun 15, 2014
	HR-02B	MDU TPS-Nose Segment	1	Jun 15, 2014
Option 2	HR-03	Sub-Scale MDU Support Structure	1	Jun 15, 2014
Option 3	HR-04	Thick Felt with Complex Curve Demonstration Unit	1	July 30, 2014
Option 4	HR-05A	MDU TPS-Gore Segments	12	TBD (2015)
	HR-05B	MDU TPS-Nose Segment	1	TBD (2015)

* Molds for SPRITE TPS Segments will be provided by NASA.

2.0 APPLICABLE DOCUMENTS

All applicable documents are listed below:

- US Patent #5,536,562 Tran, et al. July 16, 1996 – PICA fabrication process.

3.0 TASK REQUIREMENTS

3.1 GENERAL

NASA's Contracting Officer Representative (COR) will serve as the primary point of contact between NASA and the contractor for all technical and programmatic issues related to this SOW. The NASA Contracting Officer (CO) will serve as the primary contact for all contractual issues.

a) The contractor shall provide management of all resources, schedule, procurement, quality control, and documentation control to deliver the services and products required.
b) The contractor shall designate a single individual who will be given full responsibility and authority to manage and administer all aspects of the work specified in this SOW, and ensure that all objectives are accomplished within schedule and cost constraints.
c) The contractor shall designate a single individual who shall serve as the point of contact with the COR for all technical and programmatic aspects of the contract.
d) The contractor shall designate a single individual who shall serve as the point of contact with the CO for all contractual aspects of the contract.

3.2 PLANNING AND COORDINATION

The contractor shall participate in technical interchange meetings or other meetings to discuss technical or programmatic issues as requested by COR. After contract award, the COR will determine the frequency and the method for progress reporting. Examples of technical interchange meetings expected during this contract are:

- Monthly and/or impromptu telecons to discuss schedule
- Weekly and/or impromptu telecons to discuss unexpected process issues

3.3 SITE VISITS

a) The contractor shall support and participate in reviews, audits and site visits as requested by the Government. Specific topics and an agenda will be provided to the contractor at least two weeks prior to the scheduled reviews, audits or site visits.

b) The contractor shall provide NASA (including Government and non-Government personnel designated by NASA) access to developmental facilities, including subcontractor's facilities, for in-process inspections, audits, meetings and reviews.

3.4 SAFETY, RELIABILITY, AND QUALITY ASSURANCE

3.4.1 Materials Delivery Documentation

The contractor shall provide copies of test specimen inspection documentation.

3.4.2 Process Assessment

The Contractor shall identify the process areas that could impact the quality of the delivered product such as voids or other manufacturing defects, raw material availability, concerns associated with subcontractors, etc., whose occurrence can cause system failure, hazardous occurrence or otherwise impact the quality of the products to be delivered. The assessment shall be used in developing inspection and/or repair plans and identifying items requiring special handling, testing, or procurement controls. It is expected that this will be a continuous process and shall be updated as required throughout the period of performance of the contract.

4.0 ACRONYM LIST

ARC	Ames Research Center
CA	Conformal Ablator
CO	Contracting Officer
COR	Contracting Officer Representative
DACC	Deployable Aeroshell Concepts and Conformal TPS
DR	Data Requirements
DRL	Data Requirements List
EDU	Engineering Development Unit
EEV	Earth Entry Vehicle
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
HRL	Hardware Requirements List
HS	Heat Shield
LDDU	Local Design Development Unit
MDU	Manufacturing Development Unit
MSDS	Material Safety Data Sheet
MSR	Mars Sample Return
NASA	National Aeronautics and Space Administration
NDE	Non-Destructive Evaluation
NIST	National Institute of Standards and Technology
OML	Outer Mold Line
PHA	Preliminary Hazard Analysis
QMS	Quality Management System
RFP	Request for Proposal
RMP	Risk Management Plan
RT	Room Temperature
SDR	Systems Design Review
SE	System Engineering
SOW	Statement of Work
SRM&QA	Safety, Reliability, Maintainability and Quality Assurance
TBD	To Be Determined
TC	Thermocouple
TIM	Technical Interchange Meeting
TPS	Thermal Protection System
V&V	Verification and Validation

5.0 DATA REQUIREMENTS

1. **DR NO.**: DR-001A/B (Preliminary and Final)

2. **TITLE**: Manufacturing Data Book

3. **DATA PREPARATION INFORMATION**:

3.1 **<u>SCOPE</u>**

The Manufacturing Data Book captures, for the Government, a clear and comprehensive summary documenting the approach the contractor develops to execute the manufacture of conformal ablative TPS in sections ~1-meter diameter. The data book shall cover each step that is necessary in the processing, handling, machining, etc. of all TPS materials and MDU components.

3.2 **<u>CONTENT</u>**

1. <u>Material Fabrication and Qualification</u>

Describe in detail the fabrication processes developed for each TPS material component. All steps, such as chemical processing, mixing, shaping, curing, autoclaving, hot/warm pressing and vacuuming, shall be included and documented. The identification of when and how all the constituents/ingredients are introduced into the process for each heat shield material component shall also be described. Estimate the time needed to create the heat shield material as a function of size (i.e., volume or acreage area).

Describe limitations of current production techniques or equipment and discuss any changes that will be required to permit fabrication of additional coupons, sectional (joint, gap or seam) units, EDUs, and potential large-scale flight article heatshields.

Discuss necessary infrastructure changes including the addition of facilities, fabrication equipment, personnel or other resources needed to deliver additional coupons, sectional units. If there are costs associated with retention of resources for long durations, specify them.

2. <u>Non-Destructive Evaluation</u>

Describe proposed Non-Destructive Evaluation (NDE) approaches for the heat shield, including potential voids or defects that may be introduced by the proposed approaches. Include justification for heat shield material design tolerance for voids as large or larger than the NDE detectable minimum.

Discuss the inspection of coupons, sectional units, parts, sub-assemblies and MDU. Describe the actual facilities and equipment that will be used to perform these acceptance tests (prior to delivery) and any current limitations on available infrastructure.

3.3 **FORMAT**

Electronic format (Microsoft® Word or PDF)

1. **DR NO.**: DR-002 (Option 1)

2. **TITLE**: Conformal TPS Material Properties

3. **DATA PREPARATION INFORMATION**:

3.1 **SCOPE**

TPS material properties are used in the development of thermal response models for TPS sizing and heatshield design. If this optional DR-002 is exercised, the contractor shall provide testing and a subsequent test report summarizing the results of the material property evaluation of the contractor-supplied conformal TPS manufactured under this contract.

3.2 **CONTENT**

Conduct material property evaulations on a minimum of ***5 samples per data point*** for each of the properties listed in the table. Provide a report summarizing test results, describing any anaomolies and provide raw data for analysis by NASA.

Material Property	Property Range	Test Method
Density	Room Temp	Bulk
Thermal Conductivity	RT to 250C	Comparative (ASTM E 1225) or Guarded Hot Plate (ASTM C177)
Heat Capacity	RT to 250C	Adiabatic Drop Calorimetry (ASTM D 2766)
TGA	RT to 1200C	ASTM D 3850
Modulus	Room Temp	ASTM D 4762
Tensile Strain to Failure (IP)	Room Temp	ASTM D 4762
Tensile Strain to Failure (TTT)	Room Temp	ASTM D 4762

3.3 **FORMAT**

Electronic format (Microsoft® Word or PDF)

6.0 HARDWARE REQUIREMENTS

The contractor shall deliver the following hardware deliverables as specified below. For the items described in this Hardware Requirements List (HRL), all communication between the contractor and NASA shall be initiated with the Contracting Officer's Representative (COR), unless otherwise directed in the contract.

1. **Test Articles and Coupons**

Samples of conformal TPS manufactured by the contractor from **"1-inch" Morgan carbon felt impregnated with phenolic** will be used by NASA to evaluate physical, structural and thermal properties. Test articles and coupons required are summarized in the Table below.

Hardware Coupon Requirements

	HR #	Sample Type	Quantity	Due Date
Phase 2	HR-01A	TPS for Material Properties Testing (15"x15"x~1"thick)	2	Jan 15, 2014
	HR-01B	SPRITE TPS Segments	12	Jan 15, 2014
	HR-01C	SPRITE TC Plugs*	10	Jan 15, 2014
Phase 3	HR-02A	MDU TPS-Gore Segments	3	Jun 15, 2014
	HR-02B	MDU TPS-Nose Segment	1	Jun 15, 2014
Option 2**	HR-03	Sub-Scale MDU Support Structure	1	Jun 15, 2014
Option 3**	HR-04	Thick Felt with Complex Curve Demonstration Unit	1	July 30, 2014
Option 4**	HR-05A	MDU TPS-Gore Segments	12	TBD (2015)
	HR-05B	MDU TPS-Nose Segment	1	TBD (2015)

* Contractor to provide machined plug only, no instrumentation.
** Priced Options will not be required until exercised by the Contracting Officer via contract modification.

2. **Instrumentation**

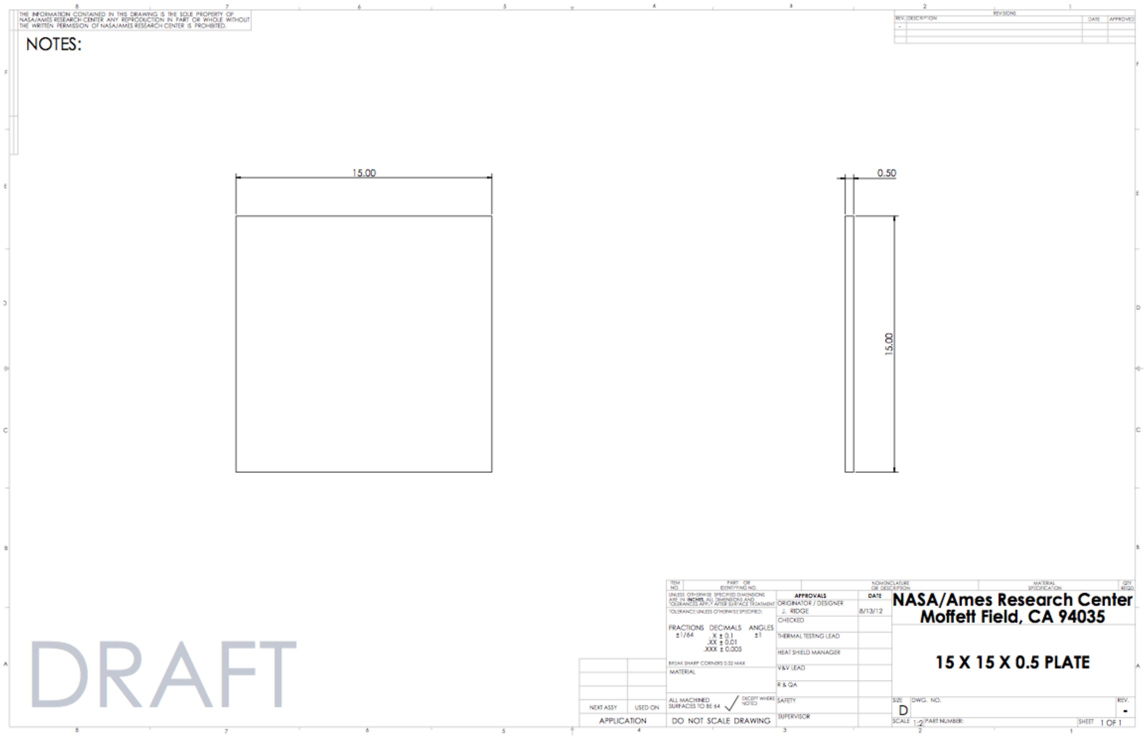
No Instrumentation is required as part of this contract.

3. **Required Testing and Documentation**

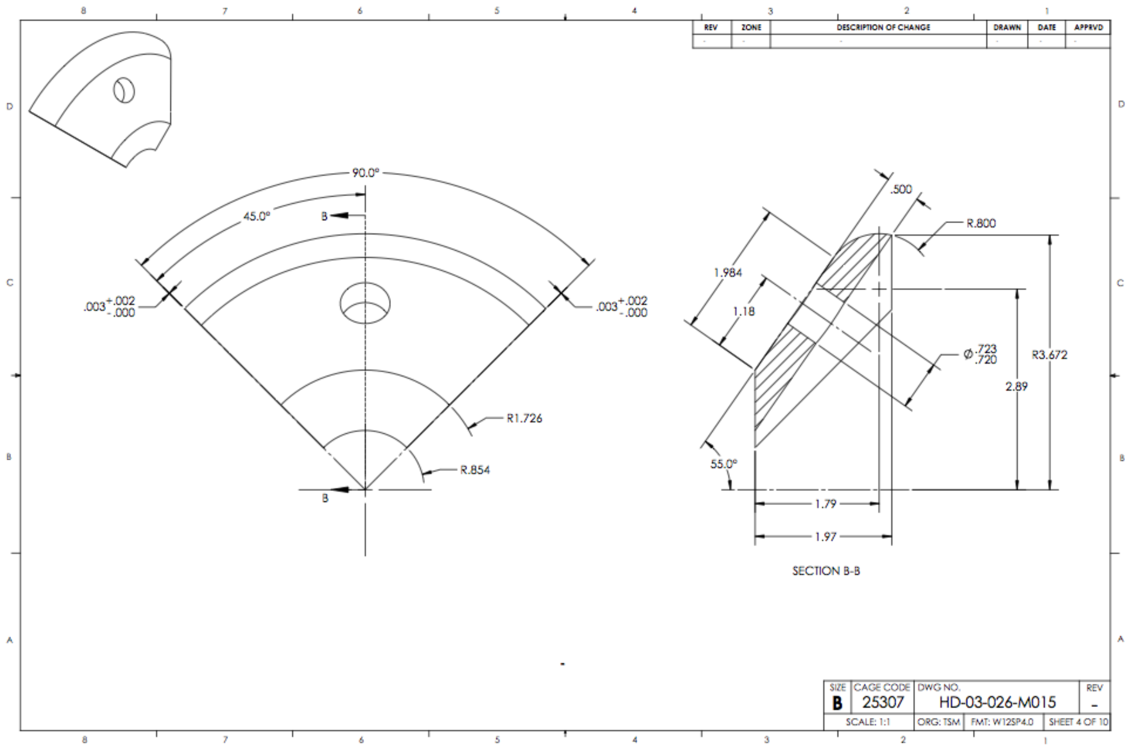
Each test coupon shall be accompanied by the traceability documentation (including unique article identifier, material lot or batch ID, etc.) and certification of inspection and compliance with the acceptance specifications as described below. Any processing non-conformance or other out of the ordinary conditions shall be documented. The contractor shall provide the following minimum information in tabular format with delivery of their specimens to NASA:

	Requirement	Acceptance Criteria	Units
1	Actual Coupon Weight	Various	g
2	Actual Coupon Dimensions	See drawing tolerances	cm
3	Actual Coupon Density	0.25-0.30	g/cm^3
4	NDE of TPS Coupon *	X-ray Image (Digital File)	N/A

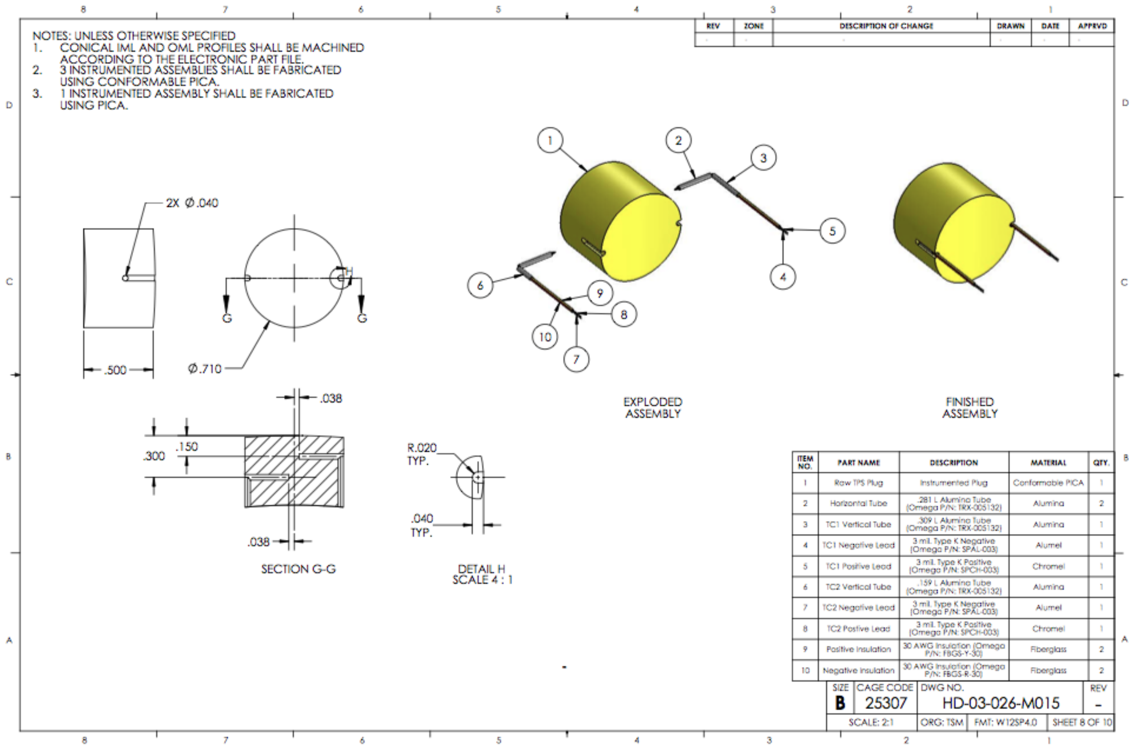
* NDE is best effort. NASA to work with contractor on acceptance standards.



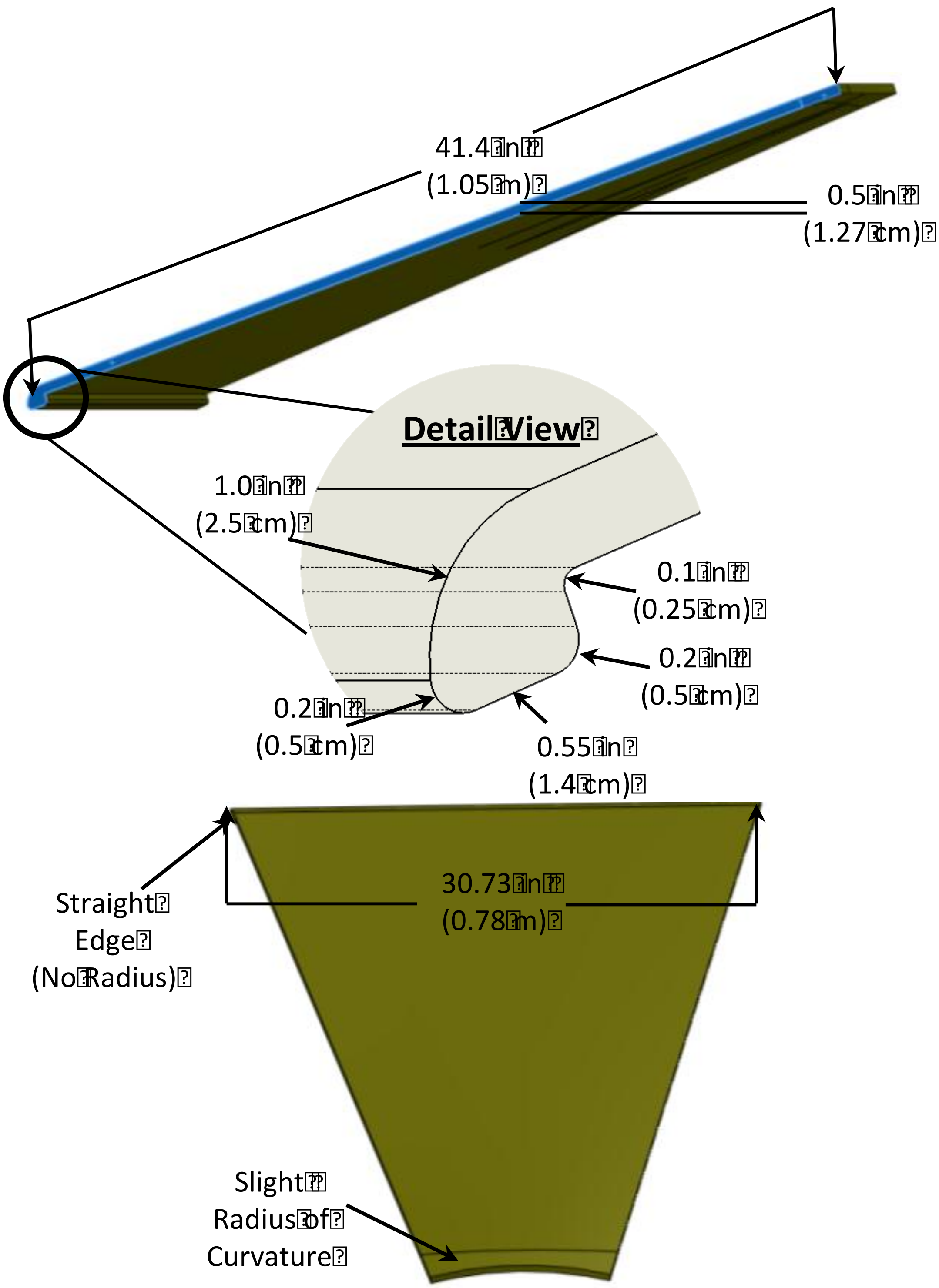
HR-01A Material Property Coupon (15x15-inch)



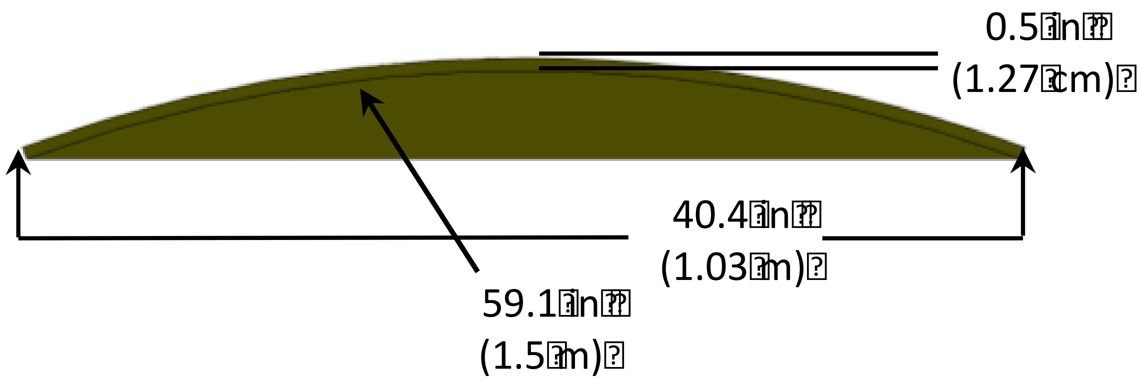
HR-01B SPRITE TPS Segments



HR-01C SPRITE TC Plug



HR-02A and HR-05A MDU Gore



HR--02B and HR-05B MDU Nose Cap